Final Report

DEVELOPMENT OF DRY FINE COAL PROCESSING TECHNIQUE

Submitted to

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Abstract

The continuing economic recovery in 2004 pushed total U.S. coal consumption to another record level. Preliminary data show that total coal consumption increased 9.4 million short tons, an increase of 0.9 percent. The electric power sector accounted for almost 92 percent of all coal consumed in the United States in 2004. Overall, it is expected that the coal production to grow more rapidly than it did in 2006 reaching over one billion tons. In 2007 and 2008, the demand of coal is projected to increase at an annual rate of about 1.4 percent each year.

Higher demand of coal will require increase in mining activities. However, mechanization in the underground coal mining industry will increase the amount of fine size coal and waste (refuse) in the mined coal. Processing of run-of-mine (ROM) coal is done at a coal preparation plant located away from the mine which means that a significant amount of rocks are also transported along with coal. Coal is cleaned using water and along with clean coal the process also generates coarse and fine refuse that need to be dispose off. Disposal of coarse is relatively easy however, fine refuse which is disposed in form of slurry, creates a serious problem for the coal companies. If the coal can be cleaned near mine mouth without using water, it will avoid transportation of rocks to a distance and also avoid the water pollution problem associated with the slurry ponds. Most of the rock can be sent back to mine with the return belt. The dry process will be economical as it will not utilize water and thus no dewatering or drying of the product will be required.

The goal of the proposed study was to evaluate a dry separation process for processing of coal finer than ¼ inch. The program was conducted as a joint program between the University of Kentucky, a coal company and an equipment manufacturing company, on two types of ROM coal obtained from different coal mines. The high ash coal samples from the Dotiki and the Warrior mines were selected for the present study. Statistical design experiments were conducted to assess the effect of operating parameters of the dry separator on product yield for a given ash content. The tests showed that for the Dotiki coal, the air table was able to reduce the ash from 27% to 10-12% ash with a clean yield of about 75-80%. The ash rejection was about 77-80% with a combustible recovery of about 95% indicating excellent separation efficiency. The pyritic sulfur was reduced from 2.65% to about 1.5%. For the Warrior coal, the clean coal yield was as high as 78% for 1/4in x 6 mesh size fraction. The 6x14 mesh fraction provided a clean coal product contaning 9% ash at a yield of 86%. The total sulfur was reduced from 3.36% to 3.05%. In summary, the air table was effective in reducing ash by 65% and sulfur by about 25-35% .

Processing of the combined -1/4″ x 6 mesh Dotiki coal reduced the ash content from 25.5% to 10.9%. The total sulfur was reduced from 4.05% to 3.35%. The heating value of the coal was increased from 10326 Btu/lb to 12623 Btu/lb. The study showed that dry separation of -1/4 in x 14 mesh coal is a feasible technology. The removal of rock at the mine site will greatly reduces the cost of transportation of coal and also improves process efficiency, if further processing of coal is required.

Introduction

The continuing economic recovery in 2004 pushed total U.S. coal consumption to another record level. Preliminary data show that total coal consumption increased 9.4 million short tons, an increase of 0.9 percent. The electric power sector (electric utilities and independent power producers) accounted for almost 92 percent of all coal consumed in the United States in 2004 [1].

Factors expected to contribute to increased coal demand and production in 2005 include:

- Continued economic recovery
- Continued increase in coal exports
- Return to normal weather patterns (colder winter weather)
- High natural gas prices
- Settlement of legal issues affecting both coal producers and consumers

Overall, it is expected that the coal production to grow more rapidly than it did in 2005. In 2006 and 2007, total domestic energy demand is projected to increase at an annual rate of about 1.4 percent each year, due to projected high prices for oil and natural gas [2].

To meet the future coal demand, the Commonwealth of Kentucky will play a significant role in supplying clean coal to the coal-burning utilities. However, increased mechanization in the underground coal mining industry to achieve higher coal output has decreased selectivity and increased the volume of refuse (waste material). The coal, therefore, has to be cleaned to meet increasingly tight specifications of consumers and government regulations.

The extraction of coal generally requires the mining of rock along with coal, whose quantity depends on the thickness of the coal seam. In certain areas of Kentucky, raw coal is being rejected due to its high content of rock, which reportedly resulted in losses of 60%-70% of coal. At current fuel prices, the transportation, processing and storage of coal containing high rock fraction significantly contributes to the production cost of the clean coal. Removal of rock from the coal at the mine site will dramatically reduce transportation and processing costs as well as provide an avenue to send back rock in the mine.

Currently, coal is processed using water. Wet processing of coal even though quite efficient requires an elaborate set up to clean the coal and is not suitable to operate near mine site. Also, wet processing of coal requires large quantities of water, of the order of 200 litres/tonne (53 gallons/tonne) [3], which is consumed as product moisture, tailings disposal and evaporation. This is equivalent to 265 million gallons of water for a 5 Mtp a mine. The consumption of such a large quantity of water would be very difficult to justify especially in semi-arid area. Furthermore, the effluent water from coal preparation plants can be acidic and could exacerbate the groundwater pollution problem. Fine refuse from the preparation plant is disposed off as slurry in a pond. There have been several incidents of impoundment breakthrough. Of these, the Buffalo Creek in W.Va in1972 and the Martin County Coal in Kentucky in the year 2000 have drawn the attention of Federal and State Governments and local people due to heavy loses of life and property.

Dry coal cleaning process, therefore, provides an alternate method compared to wet coal cleaning. The advantages of dry coal cleaning in addition to dispensing with water, offers the following advantages [3]:

- No slurry ponds or no acid mine drainage problem
- Expensive dewatering processes, such as screening, pumping, vacuum filtration or centrifuging, are not required
- No high cost processes such as thickeners, froth flotation and expensive reagents such as flocculants, collectors and frothers.
- Coal preparation plants would be smaller, cheaper, require less electrical energy and would have lower operating costs
- Freight payload would be greater and subsequently, freight cost per BTU less, due to low levels of moisture
- Absence of fine waste slurry ponds is ecologically attractive and rehabilitation costs of mining areas would be reduced
- Yields of clean coal will be relatively higher as ultrafine coal will be included with clean coal product in the product. Many coal preparation plants waste fine coal to tailings due to the cost of recovering it by wet methods and its disproportionate contribution to product moistures.

Some of the disadvantages of dry coal cleaning compared to wet washing are [3]:

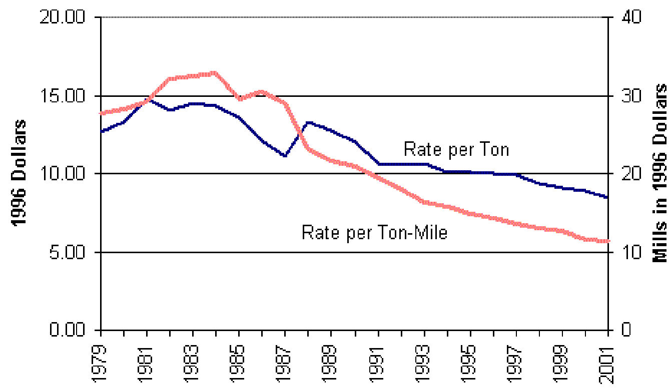
- Lower separating efficiencies, meaning that products from dry cleaning ash contents higher than the same coal cleaned in more efficient wet washing operations
- The processes are susceptible to moisture of the feed coal and in some cases partial thermal drying of feed may be required. The coal does not need to be absolutely moisture free, just sufficiently dry to allow the particles to separate
- Dry coal is more difficult to screen, particularly at fine sizes
- Dust is created by crushing, screening and some separation processes and it is necessary to enclose some machinery and install dust extraction and suppression systems
- In the past, dry cleaning equipment has generally been of low capacity. It would be necessary to develop high capacity separators to suit the high rates of outputs of modern mines and to minimize operating and maintenance costs
- Automatic quality monitoring and control systems must be developed

One of the project currently in progress at the University of Kentucky [4] at two coal mine sites in Utah has shown that the dry separation of coarse coal (-2 inch by ¼ inch) is feasible with the negligible loss of coal to the reject stream. These tests also proved that most of the disadvantages of dry coal separation mentioned above can be overcome successfully. Even though the pilot scale tests conducted by the University of Kentucky [4] proved that the efficiency of the dry separator was acceptable for coarse coal, the removal of – ¼ inch coal containing high ash content, which represented 20% -25% of the raw feed coal, reduced the overall yield of the clean coal. This fine coal could not be blended with the clean coal, which would increase the clean coal ash. Therefore, it is necessary to develop a fine coal (-1/4 inch) dry cleaning process.

<u>Potential Impact</u>:

The fine coal represents about 20% to 25% of the total feed coal, cleaning this coal would substantially increase the revenue of the mine and reduce the coal losses. The ROM coal is currently being transported an average of 20 miles to preparation plant, thus cleaning the coal near the mine site will save the transportation cost by about $6 per ton-mile (Figure 1). The dry separation of fine coal would supplement the current research work that is being carried out at the University of Kentucky on coarse dry coal cleaning.

Dry coal processing, if implemented nationally, would enhance the energy efficiency of the process by about 1.0%, which equates to annual energy savings of 270 trillion Btu with a value estimated to be around $380 million [4].



Note: 2000/2001 data are preliminary, pending missing FERC Form 580 rate data.
Source: Energy Information Administration, Coal Transportation Rate Database, 2004

Figure 1: Trends in coal transportation rates, 1979 – 2001

Background

Dry cleaning processes take the advantages of the differences in the specific gravity of coal and shale to effect their separation. In the case of dry dense medium processes, an air/magnetite or air/sand suspension is utilized rather than water/magnetite, which is commonly used in conventional dense medium cleaning process. The principles of operation of dry coal cleaning are identical to conventional wet processes, except the difference in specific gravity between air and water does have a significant effect upon the size ranges of particles that can be treated in a particular separator. The dry coal cleaning separators can be broadly classified into three groups:

- Air tables,
- Air jigs and
- Dry dense medium separators.

In Pneumatic Jig separator stratification is achieved through pulsating air and an oscillating deck. The average capacity for this jig was 100t/h, for a 2.4m x 2.7m unit. They were most effective operating at high separating densities (RD >2.0), on low-ash coal feeds (ie no middlings). Top size of feed was usually restricted to 25mm and, in general, the middlings/discard was retreated through a wet processing plant to maximize combustible recovery. Ep of the process was usually 0.3-0.4 indicating poor separation. Feed size ratios were restricted to 4:1 for optimum results [6].

The Pneumatic Tables came in various forms, such as the SJ-Type, the V-Type and Y-Type. The principle is similar to that of a wet concentrating table, with a slightly tilted table surface, covered with a fine mesh cloth, through which a constant velocity upward air current was passed. Feed was introduced at one end, while oscillation of the table allowed this to traverse across the unit and the mechanical and pneumatic forces facilitated stratification of the material. The heavier particles settled to the bottom where further movement down the table was hindered by riffles, travel being in the direction of the deck's vibration. The lighter particles remained in the upper layers and passed over the riffles, traveling under gravity down the slope of the deck and being separated into middlings and coal at the end by splitter plates. Earlier models had a limited capacity of 20 t/h and feed top size was restricted to <7mm, with a maximum feed size ratio of 4:1 [6]. However, recent models accept a top size of 3 inch (75 mm) with a higher capacity of more than 300 tph. In the present project, a dry separator based on the principles of pneumatic air table was fabricated and tested.   This equipment is simple to operate and requires less maintenance.

Theory

Because of so many interactions between the suspending medium and the particles of varying size, shape and specific gravity occur simultaneously, till now no completely satisfactory theoretical models have been developed. Because of the complexities involved in developing theoretical models, numerical methods are being developed to understand the settling of the particles [5].

The theory of equal settling of particles developed by Rittenger in 1867 gives an insight to the settling of particles of various diameters and specific gravities which would each have equal terminal velocities falling through a medium of specific gravity ρ_f. The settling ratio is equal to limiting ratio of diameters of particles which may be separated by free settling.

$$Settling\ ratio = \frac{d_L}{d_H} = \frac{\rho_H - \rho_F}{\rho_L - \rho_F}$$

Where d_L = diameter of particles of specific gravity ρ_L

d_H = diameter of particles of specific gravity ρ_H and $\rho_L < \rho_H$

Thus, for particles of coal (sp.gr. 1.40) and shale (sp.gr. 2.60) settling in air (sp. gr ≈ 0), the settling ratio is equal to 1.86 or about 2. In other words spherical particles of coal and shale may be separated while falling in air if they are within a 2:1 ratio. However, if the air is replaced by water, the settling ratio will be 4.0. Thus a simple water medium process separation is theoretically possible within a 4:1 size ratio, as compared to a 2:1 size ratio for an air medium separator.

If the effective bed density is used rather than the fluid medium density, thus simulating the buoyancy effect of the interacting bed of particles, a modified value called as the hindered settling ratio, may be calculated. For example, with a 25% shale plus 75% coal mixture at 40% solids by volume we get hindered settling ratios 2.8 and 21.0 in air and water mediums respectively.

In both jigs and tables a controlled oscillating motion is used to assist stratification of the bed of particles. Differential acceleration has been recognized as playing an important role. Figure 2 shows the theoretical settling ratio of particles for air as a medium. It shows that a settling ration of 40:1 exist after 0.005 seconds free fall, decreasing to 5:1 after 0.02 seconds, and to 2:1 at more practicable time intervals. For water as a medium a settling ratio of 40:1 existed after as much as 0.12 seconds.

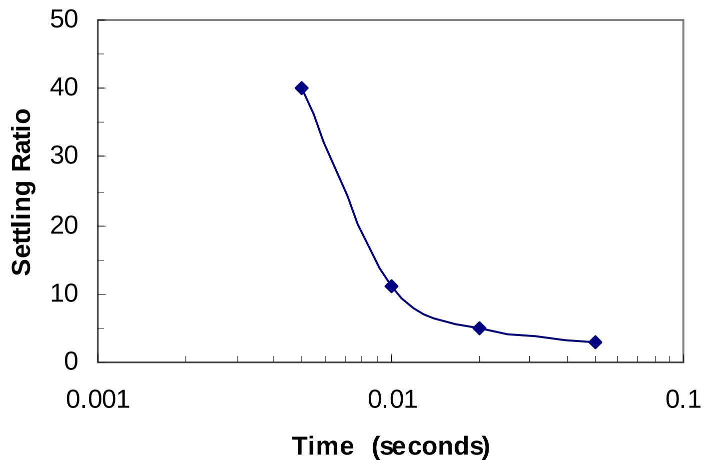


Figure 2: Settling ratio against free falling time for coal-shale particles in air

Even though, these theoretical approaches give only partial explanations, however, they do confirm that:

- a restricted size range is logical for air jigs and tables
- high frequency oscillations would be necessary for efficient separation of a wide size range of particles in an air medium separators.

Objectives

The main objective of the proposed program was to develop and evaluate an advanced dry coal cleaning technology for processing fine size coal of -1/4 inch x 14 mesh size. It is also the objective of the proposed research to utilize the experimental data to obtain operational technical data for a pilot-scale operation.

Results and Discussions

Acquisition and Characterization of Samples

The University of Kentucky Center for Applied Energy Research (UKCAER) collected Run-of-mine coal samples containing high ash from two (Warrior and Dotiki) coal mines located in the Western Kentucky. The samples were crushed to -1/4 inch and were further screened to obtain -1/4″ x 6 mesh, -6 x 14 mesh and – 14 mesh fractions. The properties of each size fraction are given in Table 1.

Table 1: Properties of the Warrior and the Dotiki coal samples.

Sample ID	Particle Size	Ash %	Moisture %	Volatile Matter %	Fixed Carbon %	Total Sulfur %	Pyritic Sulfur %	Sulfate Sulfur %	Organic Sulfur %
Dotiki	1/4 in x 6 mesh	29.17	3.54	30.23	37.06	3.92	2.55	0.11	1.26
	6x14 mesh	24.41	3.65	31.97	39.97	4.19	2.75	0.13	1.31
	-14 mesh	21.18	4.08	33.26	41.48	4.11	2.3	0.15	1.66
Warrior	1/4 in x 6 mesh	22.48	4.66	33.27	39.59	3.69	2.05	0.17	1.47
	6x14 mesh	21.62	5.17	33.48	39.73	3.68	1.84	0.2	1.64
	-14 mesh	23.09	6.49	32.69	37.73	3.63	1.84	0.28	1.51

The 1/4″ x 6 mesh Dotiki sample contains slightly higher ash (29%) compared to 6x14 mesh and -14 mesh fractions. The data shows that as the particle size becomes smaller, the ash content decreases from 29% to 21%. The pyritic sulfur content average about 2.53%; whereas sulfate and organic sulfur is fairly uniform in all size fractions.

The ash content in the Warrior coal is uniformly distributed in all size fractions. The average ash content of Warrior sample is about 22%. The ¼″ x 6 mesh sample contains slightly higher pyritic sulfur (2.05%) compared to other two fraction (1.84%), indicating concentration of pyrite in this size fraction.

Sink-float tests were carried out on ¼″ x 6 mesh and 6x14 mesh size fractions of the Dotiki sample to determine the clean ability as a function of separating density. The analysis was conducted using the ASTM static bath procedure using lithium meta-tungstate solution as the heavy medium. Each density fraction was rinsed, dried and prepared for ash analysis. Figure 3 shows the float-sink data conducted at selective separation densities in the form of variation of cumulative product ash with cumulative product yield. Figure 3 also shows the ideal separations of different size the Dotiki coal fractions. The figure shows that both size fractions have similar cleaning characteristics. It can be seen that at about 10% product ash, the ideal clean coal product yield will be around 85%.

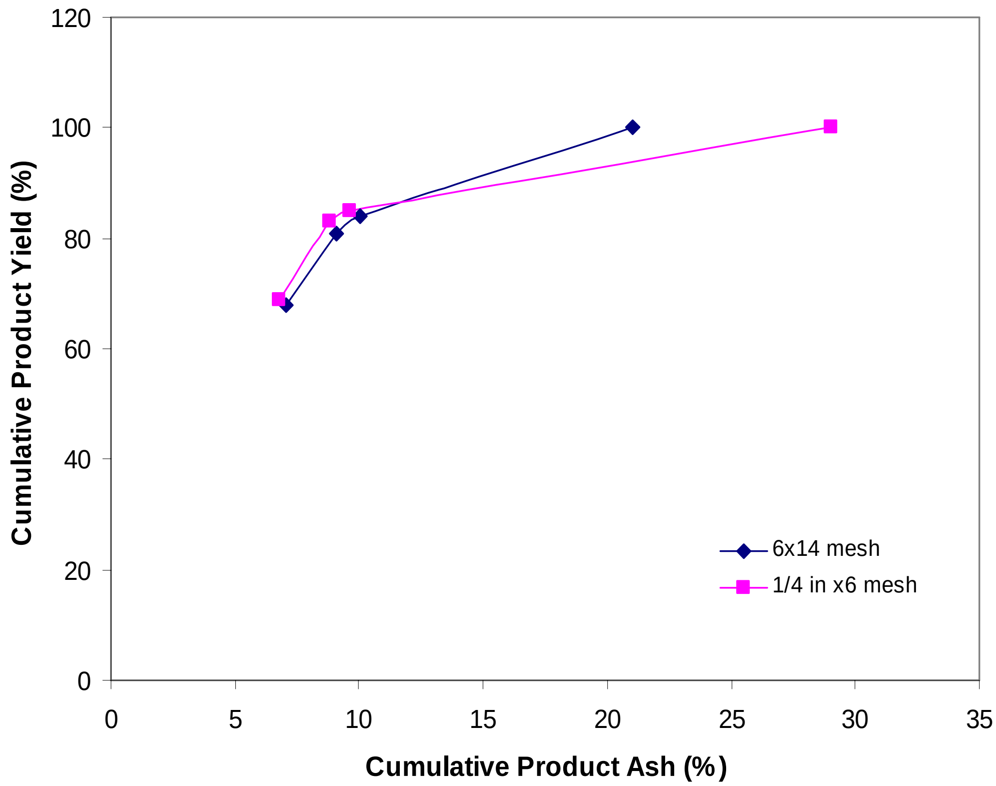


Figure 3: Float-Sink data for Dotiki ¼″ x 6 mesh and 6x14 mesh coal size fractions.

Air table Separation study

At present an air table capable of processing fine coal is not available. Hence, an air table, supplied by the Bratney Companies, Des Moines, Iowa, used for de-stoning of grains (Figure 4) was used for processing of coal. The equipment was ordered with electronic controls to adjust the operating parameters. The air flow rate, table frequency and feed rate could precisely be adjusted using process control. The table longitudinal and transverse angles could be adjusted manually. Earlier it was decided to replace the air blower to provide higher airflow rate for coal particles. However, preliminary tests showed that the existing air blower is capable of lifting coal particles that were used in the present study. Similarly, the existing riffles were found to be adequate for movement of shale particles. A dust collection system used to capture the dust generated to maintain the safe working environment.

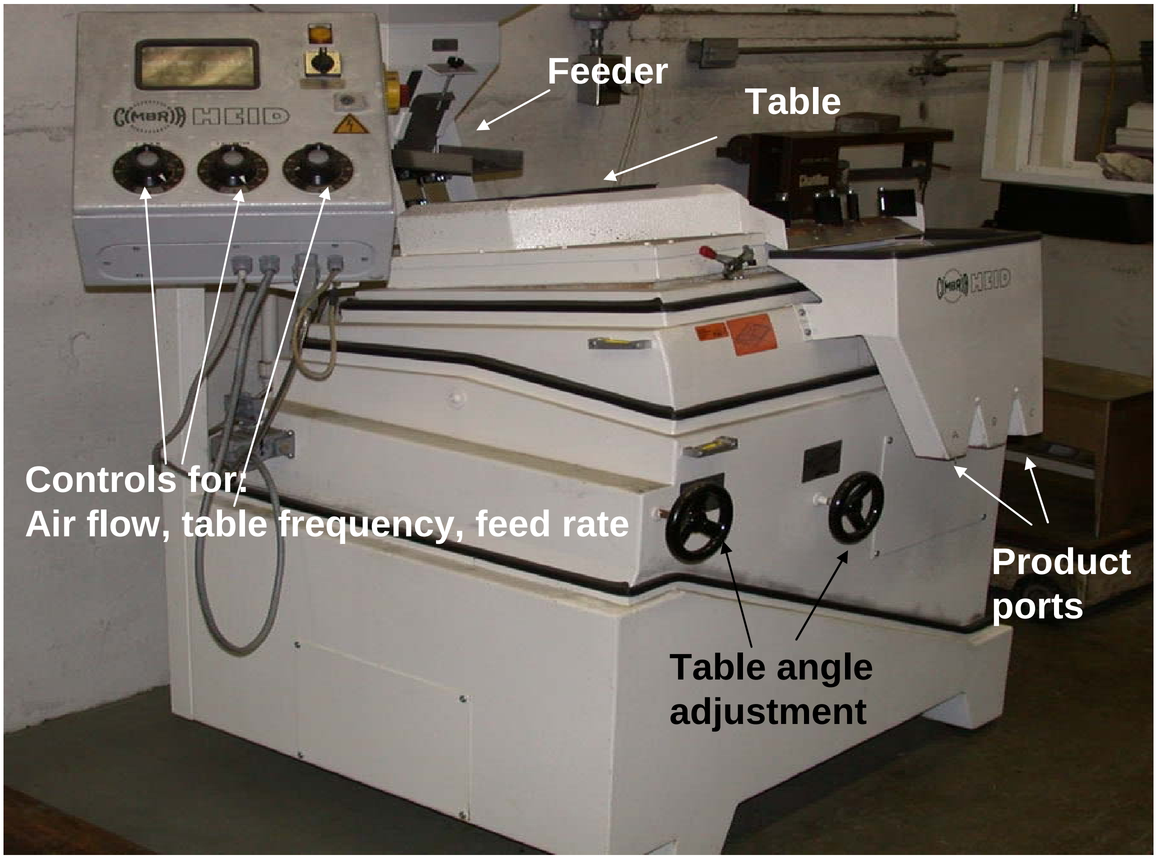


Figure 4. Laboratory air table used for the present study

Figure 5 shows the layout of the table where separation takes place. It can be seen that lighter particles take a longer route to the discharge end. This provides longer residence time for coal and shale particles to achieve proper separation. Hence, this particular air table was selected for the present study.

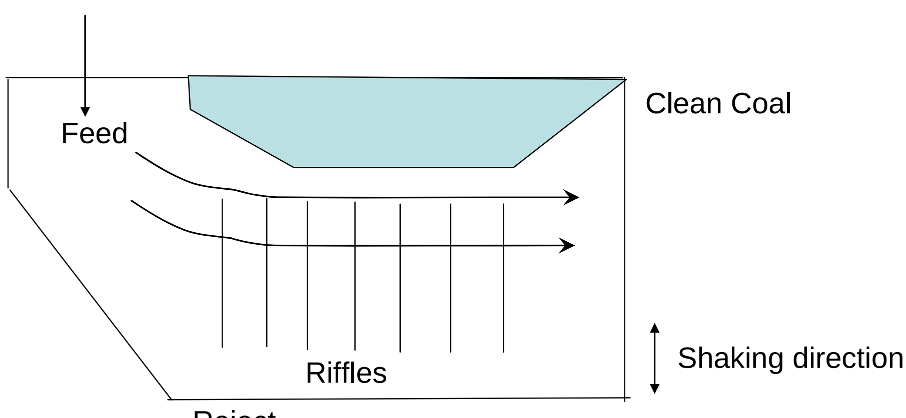


Figure 5: Layout of the air table

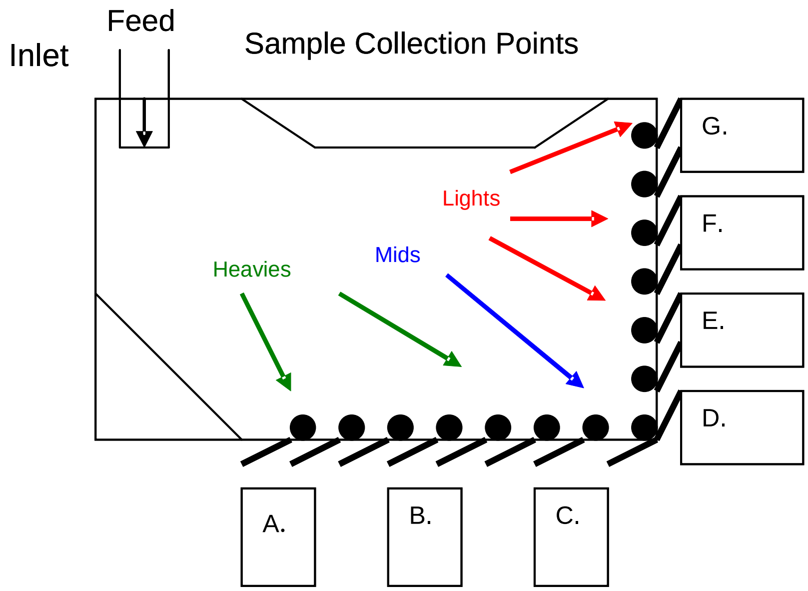


Figure 6: Sample collection points of the air table

Figure 6 shows the flow of different particles on the air table. The heavier particles such as shale, quartz and pyrite move towards the ports numbered A, and B. Where as middling particles, which is a mixture of unliberated coal and shale, moves towards the ports C and D. The coal particles being lighter move towards the ports E, F and G. During the study it was observed that closing the port D provided better separation probably due to increased residence time on the table. For the present study samples were collected from ports A, B, C, E, F and G. The port C and E were opened just enough to allow a small movement of particles on the table, generally resulting in a very small amount of sample (Figure 7) which was combined with samples from neighboring ports.

Figure 7: Sample reporting to port C during air table operation

Evaluation of air table parameters and optimization

There are a number of process and operating variables associated with the unit, it was necessary to optimize the key variables that greatly influence the separation efficiency. Based on the earlier experiments conducted with coarse coal (2″ x ¼″) the three table variables, namely, table frequency, longitudinal and transverse angles were examined in the present study. The fluidization air flow rate was kept constant at 50Hz. A statistically designed set of experiments using Box-Benkhen design was conducted on the air table to determine the most significant operating variables. The variables and their respective value range used for the statistical design were:

Table frequency (30 -50 Hz) (A)
Longitudinal angle (0.5 -2.0 degree) (B)
Transverse angle (5.0 -8.0 degree) (C)

The Box-Benkhen design and responses are listed in Table 2 and 3 for Dotiki 1/4″x 6 mesh and 6 x 14 mesh size coal fractions, respectively. The data showed that the clean coal ash content varied between about 10-13% within the test matrix. This clearly shows the flexibility of the equipment providing product ash content with less variation with a wide change in operating variables. Hence, it was decided to analyze the data for a constant product ash, as there was no significant change in product ash contents. The Tables 2 and 3 show the product yields for 12% and 11% ash respectively.

Table 2. Box-Benkhen experimental program for Dotiki (1/4″x 6 mesh) coal

Table Frequency (Hz)	Longitudinal Angle (degree)	Transerverse Angle (degree)	Product Yield (%)
30	0.5	6.5	75
50	0.5	6.5	62
40	1.25	6.5	68
30	1.25	8	56
40	1.25	6.5	74
40	2	5	78
40	1.25	6.5	76
40	1.25	6.5	73
50	1.25	5	62
40	2	8	66
40	1.25	6.5	70
50	1.25	8	50
50	2	6.5	68
30	2	6.5	80
40	0.5	5	73
30	1.25	5	80
40	0.5	8	55

Table 3. Box-Benkhen experimental program for Dotiki (6 x 14 mesh) coal

Table Frequency (Hz)	Longitudinal Angle (degree)	Transerverse Angle (degree)	Product Yield (%)
30	0.5	6.5	73
50	0.5	6.5	67
40	1.25	6.5	80
30	1.25	8	55
40	1.25	6.5	78
40	2	5	82
40	1.25	6.5	78
40	1.25	6.5	76
50	1.25	5	77
40	2	8	66
40	1.25	6.5	75
50	1.25	8	40
50	2	6.5	50
30	2	6.5	81
40	0.5	5	70
30	1.25	5	85
40	0.5	8	52

Empirical models describing the product yield as a function of the operating parameter values can be written respectively for Dotiki 1/4″x 6 mesh (Eq. 1) and 6 x 14 mesh (Eq. 2) coal size fractions as,

$$\text{Yield (\%)} = 2.62 + 0.76 \times \text{Table Freq.} + 4.5 \times \text{Long. Incl.} + 24.58 \times \text{Trans. Incl} + 0.2 \times \text{Table Freq.} \times \text{Trans. Incl} - 0.033 \times \text{Tab. Freq.2} - 2.92 \times \text{Trans. Incl}^2 \quad [1]$$

$$\text{Yield (\%)} = 150.8 - 0.75 \times \text{Tab. Freq.} + 2.83 \times \text{Long. Incl.} - 8.41 \times \text{Trans. Incl.} \quad [2]$$

The coefficients of Eqs. [1] and [2] and their significance are provided in Tables 4 - 5. The associated p-values ("Prob > |F|") are interpreted as the probability of realizing a coefficient as large as that observed, when the true coefficient equals zero. In other words, small values of p (less than 0.05) indicate significant coefficients in the model.

Table 4 shows that all three parameters are important for Dotiki ¼″ x 6 mesh coal, where as for 6x14 mesh fraction (Table 5), only the table frequency and the transverse angles are important as indicated by the ‘F’ values. It was surprising to note that the longitudinal angle was not an important parameter for the product yield. It was expected that the product yield will increase with increase in longitudinal angle due to the increased slope towards product discharge end. During the testing, it was observed that the coal particles are easily lifted by upward air flow rate and move rather quite freely towards product end. Hence, the longitudinal angle might not have had the expected effect on the product yield. The effects of each parameter on the product yield are pictorially depicted in the perturbation graphs (Figs. 8 and 9). The quadratic nature of the curves A and C shows that table frequency and transverse inclination are important parameters (Fig. 8). This conclusion is supported by the very low value of 'F' values. An increase in transverse inclination increases the product yield. This could be attributed to the higher volumetric flow rate of solids to the product end, which removed higher fraction of stratified material from the table thus, increasing the cut point. The higher table frequency in both cases decreases the product yield, thus indicating larger movement of material towards tailings end. During the testing with coal fractions, it was observed that the entire particle bed move faster towards tailings discharge end. This behavior may be due to the fact that because of higher table frequency the particles move on the table even before they had chance to be stratified.

Table 4 : Analysis of varience table for Dotiki 1/4″x 6 mesh size fraction

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	1213.47	6	202.25	23.89	< 0.0001	significant
A-Tab. Freq.	300.12	1	300.12	35.46	0.0001	
B-Long. Incl.	91.13	1	91.13	10.77	0.0083	
C-Trans. Incl	544.5	1	544.5	64.33	< 0.0001	
AC	36	1	36	4.25	0.0661	
A^2	47.16	1	47.16	5.57	0.0399	
C^2	183.48	1	183.48	21.68	0.0009	
Residual	84.64	10	8.46			
Lack of Fit	43.84	6	7.31	0.72	0.66	not significant
Pure Error	40.8	4	10.2			

Table 5: Analysis of varience table for Dotiki 6 x 14 mesh size fraction

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	1761.25	3	587.08	8.05	0.0028	significant
A-Tab. Freq.	450	1	450	6.17	0.0274	
B-Long. Incl.	36.12	1	36.12	0.5	0.494	
C-Trans. Incl	1275.12	1	1275.12	17.48	0.0011	
Residual	948.28	13	72.94			
Lack of Fit	933.08	9	103.68	27.28	0.0031	significant
Pure Error	15.2	4	3.8			

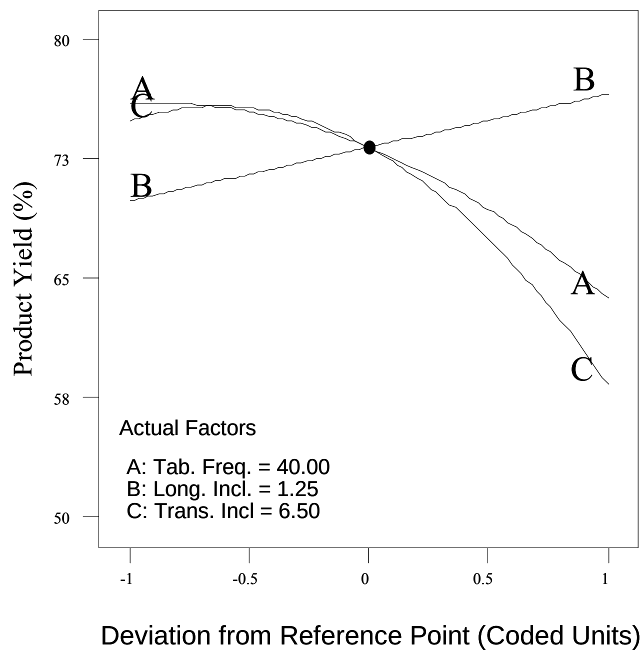


Figure 8. Perturbation plots showing the parameter effects on product yield. (Dotiki ¼″ x 6 mesh).

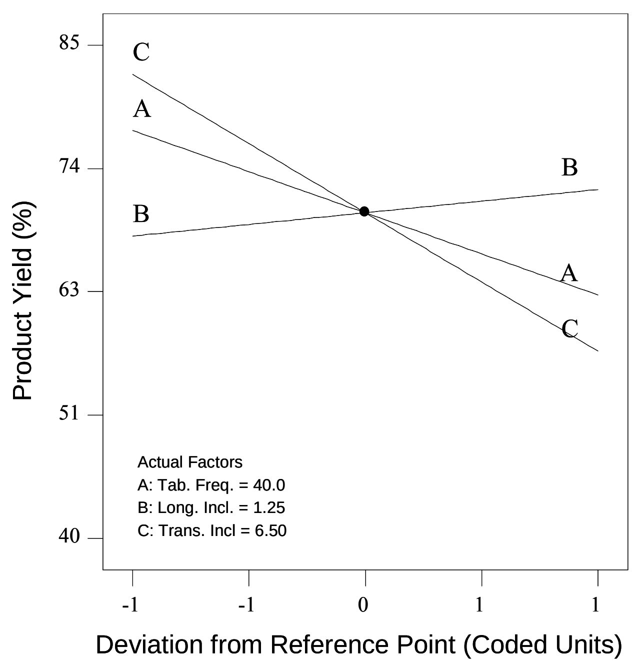


Figure 9. Perturbation plots showing the parameter effects on product yield. (Dotiki 6x14 mesh).

The effects of the longitudinal inclination and the table frequency are pictorially shown in Figures 10 and 11 for both Dotiki size fractions. These figures clearly show that an increase in table frequency decreases the product yield. In case of Dotiki ¼″ x 6 mesh size fraction longitudinal angle increases the product yield, however, for 16 x 6 mesh size fraction it does not have any affect. The interactive effect of transverse inclination and table frequency is shown in Figure 12 for Dotiki ¼″ x 6 mesh size fraction. At a transverse inclination of 5° and table frequency of 30 Hz the yield is about 71%. However, at the same transverse inclination of 5°, an increase in table frequency from 30 Hz to 50 Hz decreases the product yield from 71 % to about 60%. Conversely, at a transverse inclination of 8°, increasing the table frequency reduced the yield from 59% to 50%. This decrease in product yield is mainly due to the transportation of material towards tailings end without stratification.

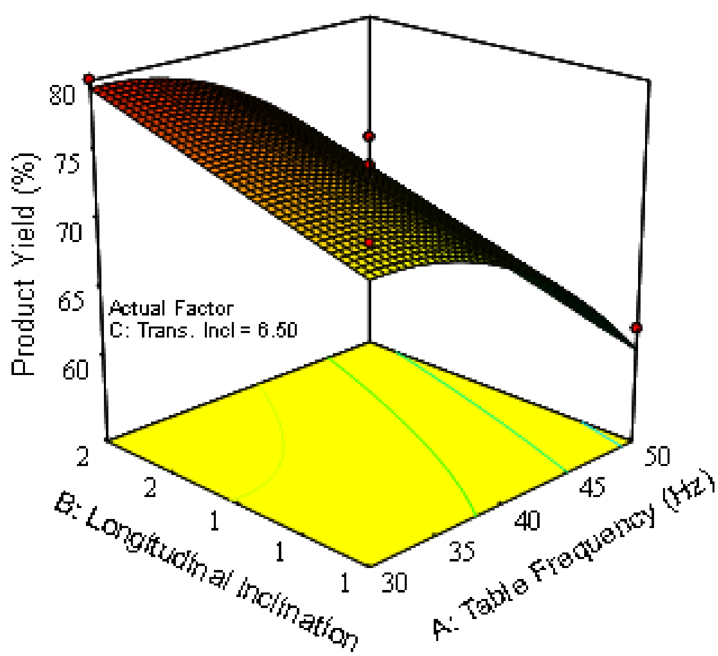


Figure 10. Plot illustrating the effect of longitudinal inclination and table frequency (Dotiki ¼″ x 6 mesh).

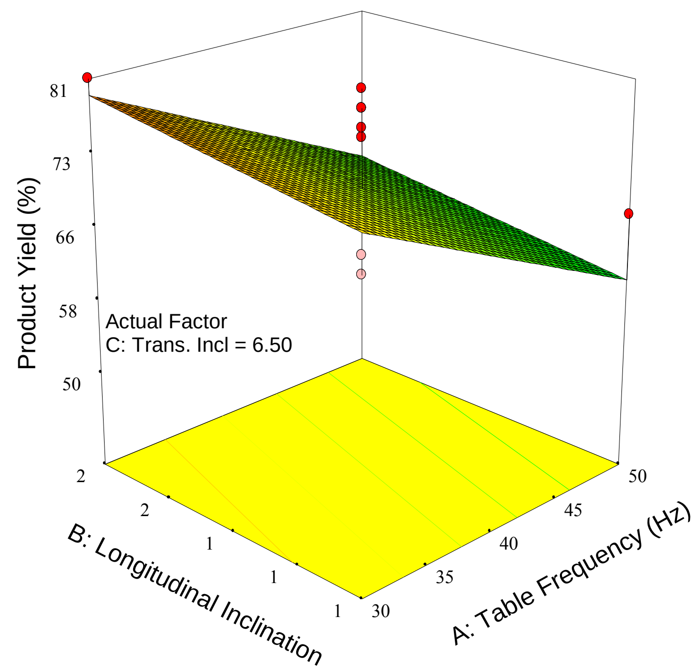


Figure 11. Plot illustrating the effect of longitudinal inclination and table frequency (Dotiki 6x14 mesh).

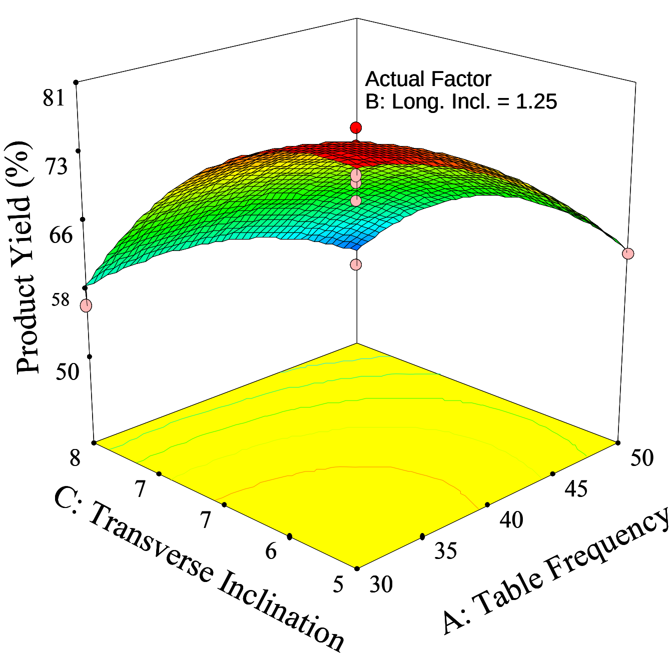


Figure 12. The interactive effect of transverse inclination and table frequency on the product yield. (Dotiki ¼″ x 6 mesh)

Equations 1 and 2 were used to optimize the yield or achieving maximum separation efficiency. A steepest ascent/descent optimization routine was utilized to maximize/minimize the desirable merit function for optimization of response. The goal was to maximize the product yield by changing the table operating parameters. By changing the criteria used to achieve the goal, it was possible to obtain conditions for factors under which the product yield could be maximized. These conditions are summarized in Table 11. Table 11 shows that at lower table frequency (A), the model suggest to use a lower longitudinal and transverse angles, where as at a slightly higher table frequency (38-50) higher longitudinal angle is necessary achieve a similar product yield. As explained earlier, increasing the table frequency tends to push the particles to tailings end thus reducing the particle residence time on the table, which could be compensated by increasing longitudinal and transverse angles.

Table 11. Optimized factor levels to be maintained in order to maximize the product yield

Run No.	Dotiki coal	Factor			Product Yield (%)	Desirability
		A	B	C		
1	¼ in x 6 mesh	31.55	1.25	5.12	80	1
2		36.93	1.79	5.48	78	1
3		38.36	1.90	5.55	76	1
4	6 x 14 mesh	33.22	1.09	5.13	81	1
5		37.04	1.98	5.17	80	1
6		49.15	2.00	5.00	78	1

Figures 13 and 14 show pictures of the Dotiki coal while being processed on the air table. It is clear from these pictures that the separation of rock from coal is almost perfect without losing coal to rejects. Figures 15 and 16 show the actual products obtained from the air table.

Table 12 shows the optimized air table data for obtaining product ash of 12% at a yield of 75-80%. The ash rejection was about 77-80% with a conbustible recovery of about 95% indicating excellent separation efficiency.

Table 12. Optimsed prodcut data for Dotiki coal containing about 12% ash.

Size fraction	Product Yield (%)	Product Sulfur (%)
¼ in x 6 mesh Feed ash ≈ 30%	≈ 80	≈ 1.5
6 x 16 mesh Feed ash ≈ 25%	≈75	≈ 1.4

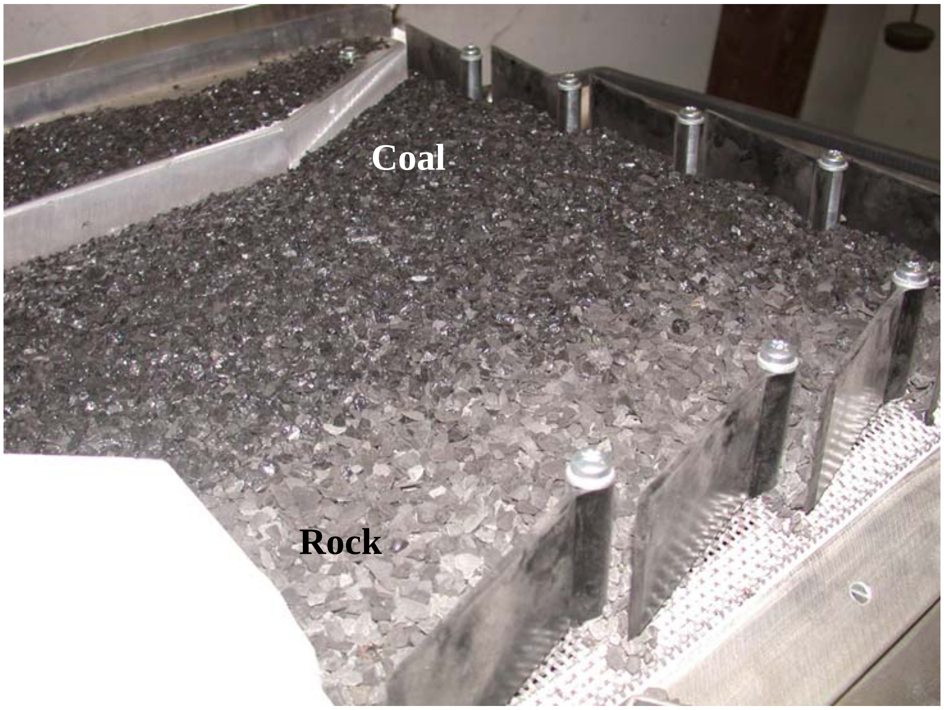


Figure 13. The separation of coal and rock on the air table (Dotiki ¼″ x 6 mesh)

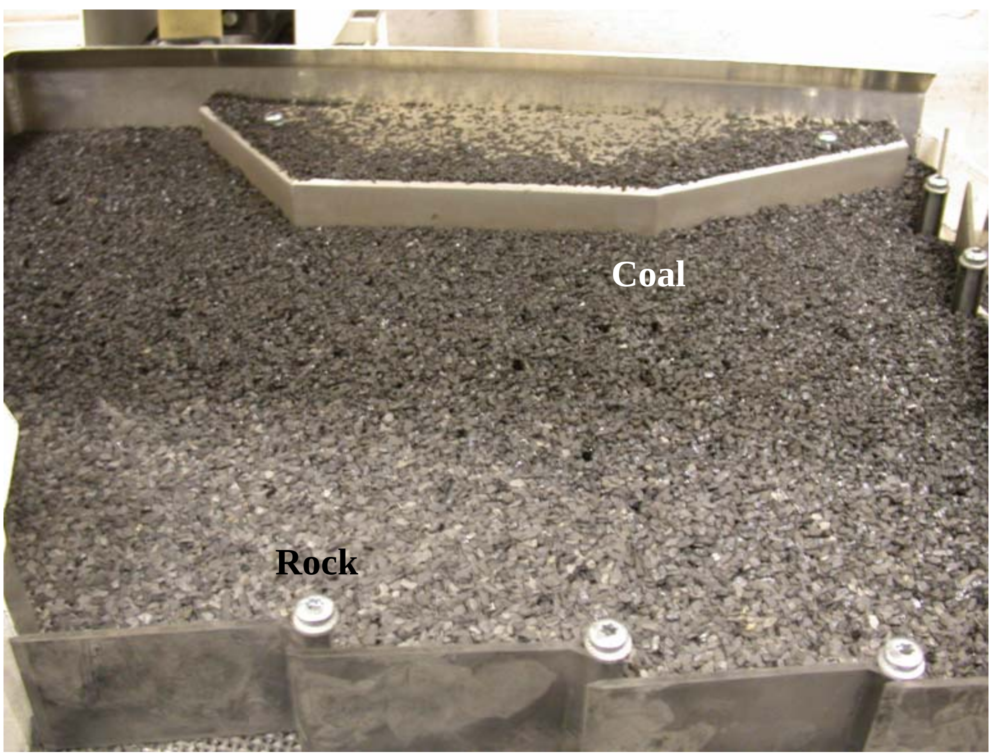


Figure 14. The separation of coal and rock on the air table (Dotiki 6 x14 mesh)

Figure 15. The reject product containing mainly rock (Dotiki coal)

Figure 16. The clean coal obtained from air table (Dotiki coal)

Separation studies with the Warrior coal

The tests conditions and results obtained for the two Warrior coal size fractions, ¼″ x mesh and 6x14 mesh are shown in Tables 13 and 14, respectively. This coal required slightly lower fluidization air flow rate compared to Dotiki coal. The air flow rate to this coal was adjusted based on the visual observation of the particle bed. At higher air blower frequency greater than 50Hz, the particle bed on the air table was completely mixed without any stratification. The 6x14 mesh size fraction required even less air flow rate (40 Hz) compared to 45 Hz required for the ¼″ x 6 mesh size fraction. Figure 17 shows a typical product recovery-grade curve for each experiment. It can be seen from the figure that the product ash fairly remains constant (7-8%) with a cumulative p[roduct yield of 70%, indicating efficient separtion of coal and rock particles.

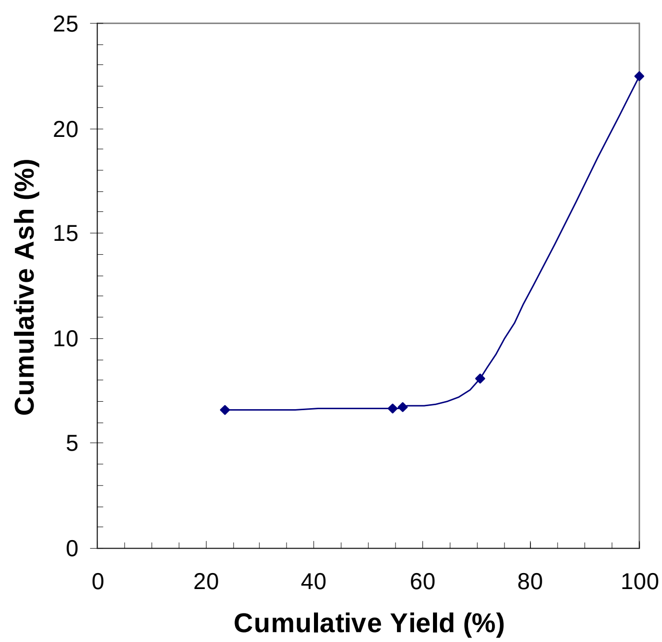


Figure 17: A typical data obtained in each experiment indicating variation of cumlative product ash with cumulative yield, Warrior coal (1/4″ x 6 mesh)

Table 13 shows that the clean coal yield is as high as 78% for 1/4″ x 6 mesh size fraction, with a reduction in total sulfur from 3.56% to 2.98%. Using 40 Hz airflow the 6 x14 mesh fraction provided clean coal containing 9% ash at a yield of 86% (Table 14). The total sulfur was reduced from 3.36% to 3.05%. Overall, the air table reduced about 25-35% sulfur and about 65% ash in the clean coal.

Table 13. Experimental parameters and results for treating Warrior 1/4″ x 6 mesh coal
Feed ash ≈22%, Feed total sulfur ≈ 3.56%, Product ash ≈ 10%.
Air blower frequency = 45 Hz

Run No	Table Frequency (Hz)	Longitudinal Angle (degree)	Transverse Angle (degree)	Product	
				Yield (%)	Sulfur (%)
1	30	0.5	6.5	75	2.91
2	40	1.25	6.5	66	2.85
3	40	2	5	60	2.83
4	30	1.25	5	78	2.98
5	35	0.5	5	76	2.92

Table 14. Experimental parameters and results for treating Warrior 6x14 mesh coal
Feed ash ≈21%, Feed total sulfur ≈ 3.36%, Product ash ≈ 9%
Air blower frequency = 40 Hz

Run No	Table Frequency (Hz)	Longitudinal Angle (degree)	Transverse Angle (degree)	Product	
				Yield (%)	Sulfur (%)
1	30	0.5	6.5	82	2.81
2	40	1.25	6.5	76	2.80
3	30	2	5	83	2.95
4	35	1.25	5	86	3.05
5	35	0.5	5	81	2.84

Figures 18 and 19 show tha air trable processing Warrior coal. The degree of separation achieved by the air table can be clearly seen in the Figure 19.

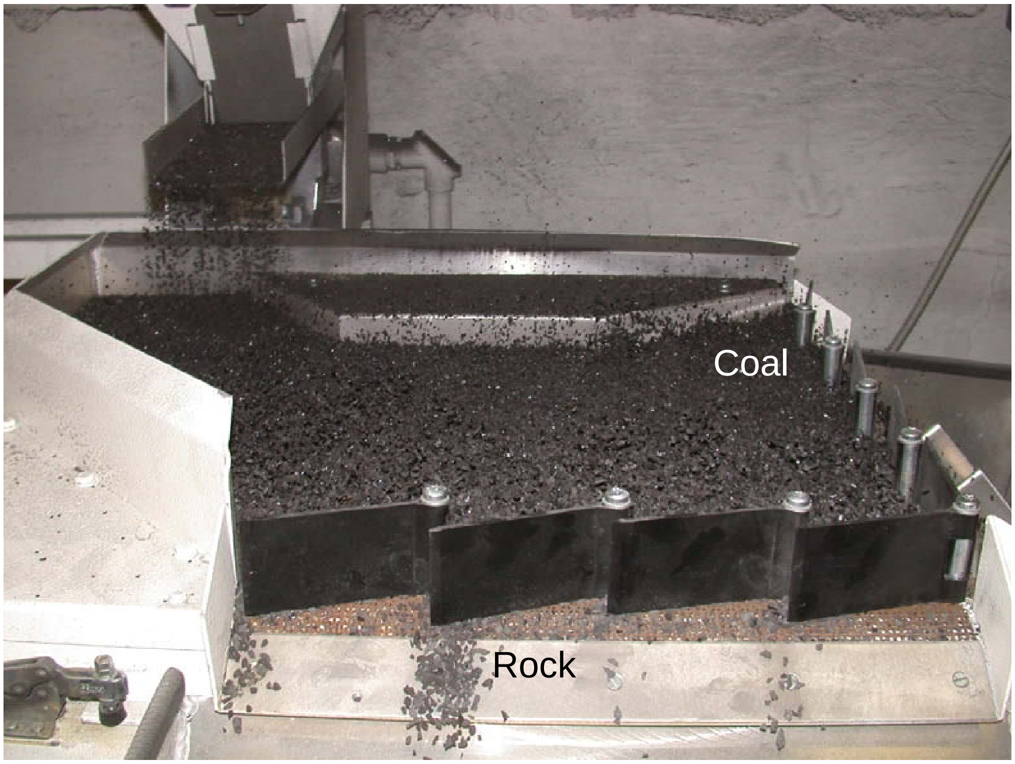


Figure 18. Air table treating Warrior coal

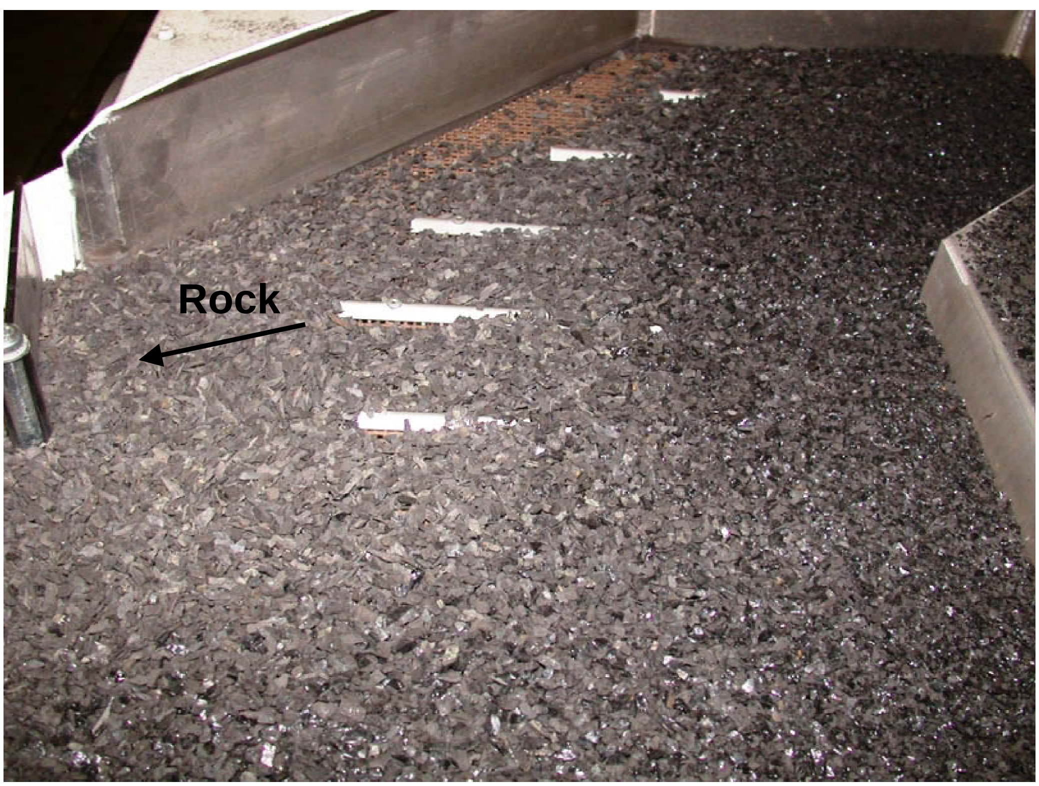


Figure 19. Separation of rock from coal on the air table while treating Warrior coal

Conclusions and Recommendations

Conclusions

- For the Dotiki seam coal, the air table used in the present study was able to reduce ash from 27% to about 10% at a yield of 80%, which was similar to the results obtained in the washability (practical limit) studies.

- For the Dotiki's 1/4″ x 6mesh size coal fraction, all three parameters; table frequency, longitudinal and transverse angles were found to be important. Where as for 6x14 mesh size fractions only table frequency and transverse angles were found to be important.

- The table frequency had a significant affect the product yield. At higher frequencies most of the particle moved towards tailings discharge end without undergoing much separation. Lower frequencies provides better clean coal yield.

- For the Dotiki coal the ash rejection was about 77-80% with a combustible recovery of about 95% indicating excellent separation efficiency. The pyritic sulfur reduced from 2.65% to about 1.5% indicating 43.3% reduction.

- Using the dry separation technique the heat content of the Dotiki coal (1/4″ x 6 mesh) was increased from 10236 Btulb to 12623 Btu/lb. The total sulfur content was reduced from 4.05% to 3.35%.

- For the Warrior coal, the clean coal yield was as high as 78% for the 1/4″ x 6 mesh size fraction. However, the 6x14 mesh fraction provided a higher yield of 86% containing about 9% ash. The total sulfur was reduced from 3.36% to 3.05%. Overall, for the Warrior coal the air table reduced about 65% ash and about 25-35% of sulfur.

- The air table study showed that dry separation of -1/4″ x 14 mesh coal is a feasible technology. The removal of rock at the mine site will significantly reduce the transportation cost of coal and will also improve process efficiency, if further processing of coal is required.

Recommendations

Based on the above conclusions it is recommended that:

- A pilot-scale continuous testing of the air table should be conducted at a coal preparation plant.
- Conduct tests with -1/4″ coal, without removing -14 mesh fraction.
- Implement proper product discharge system for larger scale operation.

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